Progress report for

Advanced Validation of AMSR Wind Speed Measurements Using Buoy, Scatterometer, and NWP Surface Analysis Products (NASA Grant #NAG5-11105).

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Summary:

The Advanced Microwave Scanning Radiometer (AMSR) is one of the most capable microwave radiometer instruments to fly in space. However, estimation of geophysical quantities from raw AMSR antenna temperature measurements requires the extensive use of empirical algorithms. On-orbit validation is thus essential to characterize the accuracy of the geophysical fields derived from AMSR data. Among the many geophysical quantities derived from AMSR (and other microwave radiometers as well), near-surface wind speed over the ice-free oceans has wide direct scientific applicability. Ocean surface wind speed is also routinely measured by in situ buoys, calculated and predicted globally by numerical weather prediction (NWP) forecast/analysis systems, and estimated independently from scattering cross-section measurements obtained from spaceborne active microwave scatterometers.

The objective of this investigation is to validate wind speed estimates from AMSR-E (on the Aqua spacecraft) and AMSR (on the ADEOS-2 spacecraft) through the use of advanced statistical analyses applied to comparisons between AMSR measurements and those from open-ocean moored buoys, NWP analyses, and spaceborne scatterometers such as the SeaWinds instruments on the NASA QuikSCAT and NASDA ADEOS-2 missions. Validation techniques explicitly designed to accommodate the non-negativity of wind speed estimates and the presence of errors in both the AMSR measurements being validated and the data sets with which they are being compared are being developed, refined, and applied. Owing to the fact that AMSR-E data became available only recently, well after the investigation began (and AMSR/ADEOS-2 was launched only on 14 December 2002 and is not expected to provide data for at least 4 months while the ADEOS-2 spacecraft is being commissioned), initial efforts were focused on developing and refining techniques using existing SSM/I and TRMM Microwave Imager (TMI) data sets. The recent availability of consistently processed AMSR-E wind speed estimates from Remote Sensing Systems has allowed the first application of advanced buoy validation techniques to AMSR-E data and a preliminary characterization of the AMSR-E wind speeds.

Progress to date can be summarized as follows:

1) Both SSM/I and (preliminary) AMSR-E wind speed measurements have been compared with open-ocean moored buoys from the U.S. National Data Buoy

Center and characterized using the random component error model of Freilich (1997) and Freilich and Dunbar (1999), enhanced to account for errors in both the data being validated (e.g., SSM/I or AMSR-E) and the comparison buoy wind speed measurements determined using the method of Freilich and Vanhoff (2002); and

2) Wind speeds derived from TRMM Microwave Imager (TMI) data have been analyzed, along with backscatter cross-sections from the TRMM Precipitation Radar (PR), to examine the relationships between radar scattering (and emission) from the ocean, winds, and sea-surface mean-square slope – this work resulted in a manuscript (Freilich and Vanhoff, 2003), available at

   http://windy.oce.orst.edu/trmm_pr_pap/fv_trmm_pr.pdf

   The paper will appear in the April, 2003 *J. Atmos. Oceanic Technology* (v. **20**, 549-562).

In the remainder of this progress report, we provide more details in particular on the buoy analyses (1). The report closes with a brief summary of the work to be performed during the remainder of the investigation.

Validation of SSM/I and AMSR-E by Comparison with NDBC Buoys:

Comparisons with open ocean buoy measurements have historically played pivotal role in the validation of remotely sensed winds (e.g., Freilich and Dunbar, 1999 and references therein; Mears et al., 2001). Such comparisons are a major (although not the sole) focus of the present investigation. To date in the project, we have extended classical buoy comparison analysis techniques and applied them to a concurrent subset of SSSM/I and (preliminary) AMSR-E wind speed measurements. The analytical extensions follow those of Freilich and Vanhoff (2002) and involve two basic assumptions:

1) The radiometer instrument error model accounts for non-negativity of wind speeds by assuming that the random "noise" in speeds measured by the radiometers can be characterized in terms of an equivalent additive random *component* error (Freilich, 1997; Freilich and Dunbar, 1999):

   $$S = \{[(\beta + \alpha W)\cos\theta + \delta\xi_x]^2 + [(\beta + \alpha W)\sin\theta + \delta\xi_y]^2\}^{1/2}$$

   where β and α are deterministic wind speed offsets and gains (respectively, W and θ are the true wind speed and direction, δ is a constant random component error magnitude (identical for both orthogonal components), and ξ_x and ξ_y are independent, normally distributed random variables with zero mean and unit variance; and

2) The comparison buoy measurements, while exhibiting no systematic errors (ie., $\beta = 0$ and $\alpha = 1$), are assumed also to be contaminated by equivalent random component error as in (1) above, resulting from instrumental errors in the buoy, representativeness errors owing to the difference between instantaneous spatial averages (characteristic of satellite measurements) and fixed temporal averages (typical of buoy data), and

spatial and temporal collocation errors between the buoy and the satellite measurement.

For the preliminary analysis shown below, non-raining wind speed measurements from all of the orbiting SSM/I instruments (RSS version 5) and (preliminary) non-raining wind speeds from AMSR-E obtained from Remote Sensing Systems were collocated with the open-ocean NDBC buoys shown as black circles in Fig. 1. Valid collocations were within 50 km of the buoy and within 30 minutes of a buoy wind speed measurement. Buoy speeds were transformed to equivalent neutral stability 10 m values using auxiliary buoy meteorological measurements as described in Freilich and Dunbar (1999). All radiometer data acquired during the period 1 June 2002 – 7 December 2002 were collocated for this analysis. When multiple radiometer measurements from the same satellite pass were within 50 km of the buoy, the measurement located closest to the buoy was used in the analysis. The constellation of 3 SSM/I satellites (F13, F14, and F15) yielded 9990 collocations, while the single AMSR-E instrument had 4004 collocations during this time period.

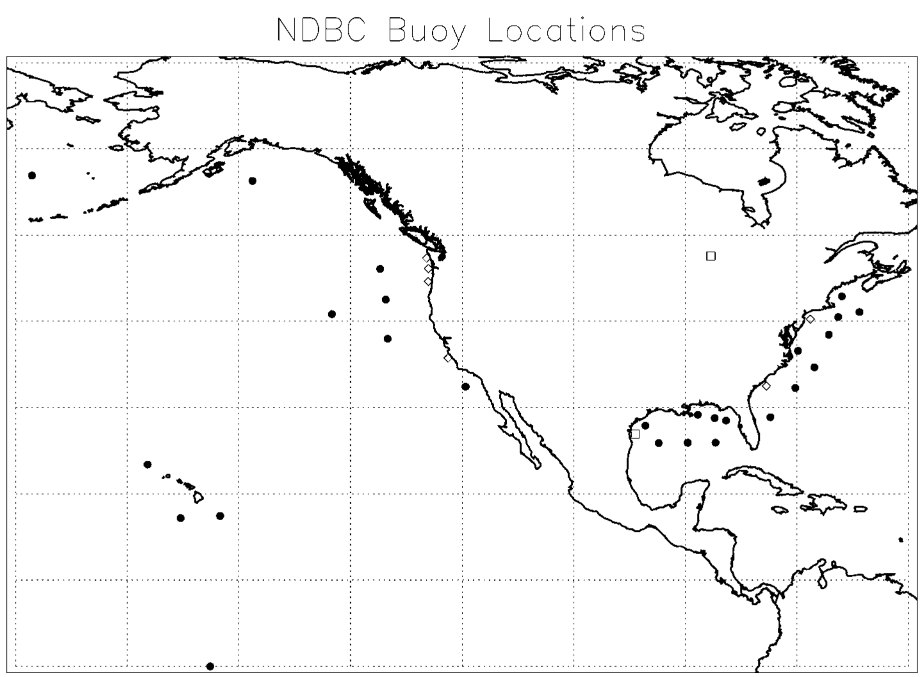

Figure 1. Locations of the 27 National Data Buoy Center open-ocean moored meteorological buoys used for this study.

For pairwise collocations such as those examined here, Freilich and Vanhoff (2002) present an analytic method for determining the Weibull parameters of the true wind speed distribution, as well as the radiometer validation coefficients α , β , and δ for arbitrary values of the buoy random component error δ_{NDBC}. Validation coefficient results are shown as a function of buoy random component error in Fig. 2. For each of the instruments, the calculated deterministic gain increases with increasing assumed buoy random component error, while the deterministic wind speed offset and the magnitude of the radiometer random component error decreases with increasing δ_{NDBC}.

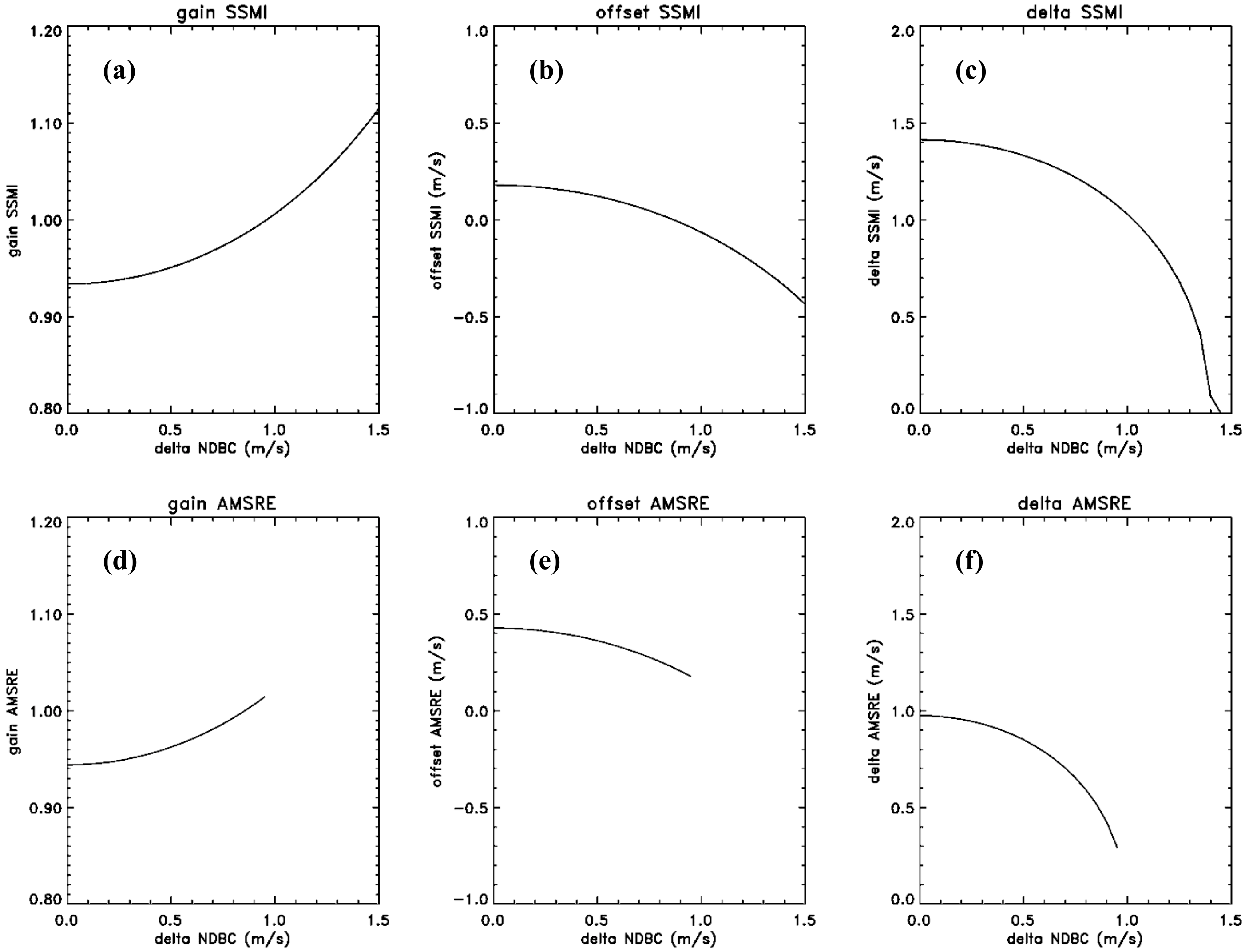

Figure 2. Calibration constants for SSM/I and AMSR-E calculated from pair-wise buoy collocations by the method of Freilich and Vanhoff (2002), as a function of assumed buoy random component error magnitude. (a) SSM/I gain; (b) SSM/I speed offset; (c) SSM/I random component error magnitude; (d-f) As in (a-c), but for AMSR-E.

Based on analysis of collocated wind measurement triplets (from NSCAT, an older version of the SSM/I data, and NDBC buoys), Freilich and Vanhoff (2002) determined effective buoy random component errors of ~0.9-1.1 m/s. Comparisons of calculated validation coefficients are presented in Table 1 for each of the sensors in the present study for assumed equivalent buoy component errors of 0 m/s (the typical case of "perfect" comparison measurements assumed in past buoy validation studies by others) and the more realistic 0.9 m/s.

Figure 2 shows that neglect of errors in the comparison measurements substantially biases the estimates of deterministic gains and offsets as well as the magnitude of random instrument errors. Proper wind speed validation and characterization of instrument accuracy thus requires direct accounting for comparison measurement errors.

	δ_{NDBC} (m/s)	Gain (α)	Offset (β, m/s)	Ran. Comp. (δ_{RAD}, m/s)
SSM/I	0.0	0.93	0.18	1.41
AMSR-E	0.0	0.95	0.42	0.97
SSM/I	0.9	0.99	0.02	1.10
AMSR-E	0.9	1.05	0.20	0.40

Table 1. Validation coefficients for SSM/I and AMSR-E, for two different assumed NDBC equivalent random component errors.

The results in Table 1 suggest that the RSS version 5 SSM/I data have negligible deterministic (gain and offset) errors for realistic values of buoy random component error. The systematic gain and offset errors are larger for the preliminary AMSR-E wind speed data examined in this study to date. However, the random component error magnitude for AMSR-E is significantly smaller than that for the SSM/I data (0.4 m/s vs. 1.1 m/s for AMSR-E and SSM/I, respectively), suggesting that AMSR-E (and later AMSR/ADEOS-2) wind speed data may eventually be substantially more accurate than SSM/I measurements, once the small remaining systematic errors are corrected. Indeed, the results of this preliminary analysis indicate that the ANSR-E wind speeds are rather less noisy (smaller equivalent random component error magnitude) than the buoy measurements with which they are being compared!

Analysis of TRMM Microwave Imager and Precipitation Radar Measurements

Although not considered in our original proposal, the TRMM Microwave Imager (TMI) wind speed measurements represent an additional well-characterized data set that can be used to quantify the accuracy of AMSR-E and AMSR/ADEOS-2 wind speeds. In preparation for using the TMI data, we performed an investigation to elucidate the relationship between wind speed, radar backscatter cross-section at low incidence angles, and centimetric sea-surface roughness using collocated TMI and TRMM Precipitation Radar (PR) data. This study was co-sponsored by this AMSR validation effort and a NASA Ocean Vector Science Team grant to the PI; the results of the investigation are applicable to both scattering and emission modeling, and thus to wind speed estimation from both radiometers and microwave scatterometers. The study capitalized on the relatively broad PR swath and its collocation with TMI wind speed data, to allow, for the first time, the use of spaceborne data for direct and separate calculation of effective ocean surface reflectivity and effective mean square slope. As noted in the summary above, this study resulted in a manuscript (shown in the reference list below as Freilich and Vanhoff, 2003) that will appear in the April, 2003 edition of the *Journal of Atmospheric and Oceanic Technology*. A preprint can be downloaded from http://windy.oce.orst.edu/trmm_pr_pap/fv_trmm_pr.pdf .

FY 03-04 Investigations

Continued AMSR wind speed validation efforts in the coming year will focus on two areas, consistent with the general plan presented in the proposal. Expansions to the originally proposed work involve unanticipated use of TMI (see Freilich and Vanhoff, 2003) and the anticipated use of SeaWinds/ADEOS-2 measurements as comparison data sets for the AMSR-E and AMSR/ADEOS-2 validation analyses.

1) *Additional Pairwise and Triplet Comparisons with NDBC buoys*
The "routine" availability of consistently processed wind speed measurements from AMSR-E, as well as continued data from the SSM/I constellation, TMI, QuikSCAT, and the NDBC buoys will allow straightforward extension of the preliminary results shown above. Substantially larger data sets will allow conclusions with greater statistical validity; the more extensive data will also allow triplet (rather than simply pairwise) calculations, thus enabling the direct determination of equivalent buoy random component errors, as well as quantification of effects resulting from small, but systematic wind directional effects on radiometer wind speed estimates. As discussed in the proposal, use of continuous buoy measurements (rather than the once per hour data, 8-10 minute averages used in all previous validations) will be explored. The continuous buoy measurements allow dynamic averaging based on measured mean wind speeds, thus allowing the effects of representativeness error to be isolated and quantified.

2) *"Global" AMSR-E Validation using SSM/I, TMI, QuikSCAT, and SeaWinds Data*
In principle, pairwise and triplet collocations between remotely sensed wind speed measurements can be used for validation without the need for buoy measurements. We will construct global pairwise and triplet collocations using existing software and analysis tools, based on data from the suite of orbiting microwave wind measuring instruments. SSM/I, TMI, and QuikSCAT data are in-hand and reasonably well characterized. As PI of the SeaWinds on ADEOS-2, the PI of this AMSR-E investigation is deeply involved in checkout and calibration/validation of that instrument – preliminary results (following initial instrument activation on 28 January 2003) indicate that the SeaWinds measurements will be as stable and accurate as those of QuikSCAT, and will be available for scientific use rapidly following the end of the NASDA ADEOS-2 spacecraft check-out period (presently planned to last until 15 April 2003). These global analyses will allow investigation of regional variations that are not possible using the NDBC buoys in the northern hemisphere alone. In addition, the use of instantaneous spatial-average measurements of equivalent neutral stability winds from satellites will greatly reduce the contributions of:

a) representativeness error resulting from fixed-period buoy temporal averaging;
b) errors introduced by the need to transform buoy data from from anemometer-height winds to 10 m neutral stability winds; and
c) the difference between the relative winds measured by the satellites (in the presence of ocean currents) and the Eulerian wind speed measured by buoys.

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